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# STUDY ON THE RECOVERY OF THERMAL ENERGY FROM TECHNOLOGICAL FLOWS IN THE COKING PLANT

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## ABSTRACT

In this paper, the current heat recovery system from delayed coking in a Romanian refinery is analyzed, the current system is simulated, and an additional heat recovery variant is proposed and simulated. Currently, the raw material is preheated with the following hot streams: light and heavy diesel (LDO and HDO) as final products of the plant and recirculated heavy diesel (RDO). After preheating the raw material, the final temperatures of the hot process streams indicate a thermal energy reserve that can be harnessed. Hot technological flows, after preheating the raw material, pass through air coolers, thus a large part of the thermal energy is lost in the environment. Since the temperature level of the hot technological flows is quite high after the preheating of the raw material - the outlet temperatures LDO is 167°C, HDO is 277°C and RDO is 245°C - the paper proposes two options for recovery of the heat from technological flows that have a reserve of thermal energy, obtaining low-pressure saturated steam. The simulation of raw material preheating systems, the actual and the proposed variant, were made with the PRO/II software.

**Keywords:** heat recovery, heat regeneration, simulation, flow

## INTRODUCTION

Heat regeneration usually represents a heat transfer from the final products discharged from the installation to the raw material that supplies the installation [1].

Heat recovery represents a useful heat transfer from the final products evacuated from the installation to a secondary fluid flow, in most cases outside the installation [1].

Coking is the most severe thermal process used in the refinery that processes the heavy products from other installations, mainly the vacuum residue from the atmospheric and vacuum distillation installation [2, 3]. The objective of the coking process is to maximize the yield of distillates in a refinery by removing large amounts of carbon from the feedstock in the form of solid coke, known as petroleum coke. The most common coking process is the delayed coking process [4-6].

The purpose of the study is to find an option for thermal energy efficiency in the heat exchange system between the technological flows in the delayed coking plant of a refinery in Romania [7].

The analyzed heat exchange system is the one in which the raw material is preheated. In the analyzed system, the raw material is made up of a mixture of vacuum residue from the atmospheric and vacuum distillation plant, as well as heavy diesel oil from the catalytic cracking plant.

At the level of the coking plant in a refinery, the raw material (RM) is preheated with the hot petroleum products resulting from the plant, LDO, HDO and with a recirculated heavy diesel oil (RDO). Figure 1 shows the principle diagram of the raw material preheating system with the hot technological streams, where the stream temperatures are specified.

- The raw material from the feed vessel enters the exchanger system with a temperature of 148°C. The raw material is preheated, in order, with light diesel oil in exchangers E1A, B, with recirculated heavy diesel oil in exchangers E2A, B and with heavy diesel oil in exchanger E3. The preheated raw material, at 265°C enters in the technological furnace to reach a temperature of 480-485°C, where the coking process begins and goes to the coking chambers.
- The light diesel oil that comes from the stripping column, with a temperature of approximately 198C, yields the heat of the raw material, then passes through air coolers to tank park with a temperature of 60°C.
- Heavy recirculated diesel from the fractionating column, with a temperature of 333°C, yields heat to the raw material, then with a temperature of 245°C it returns to the fractionating column. Heavy recirculated diesel oil is interval reflux to the fractionating column.
- The heavy diesel oil at the base of the stripping column with a temperature of 332°C yields the heat to the raw material, then passes through air coolers and reaches to the tank park with a temperature of 90°C.

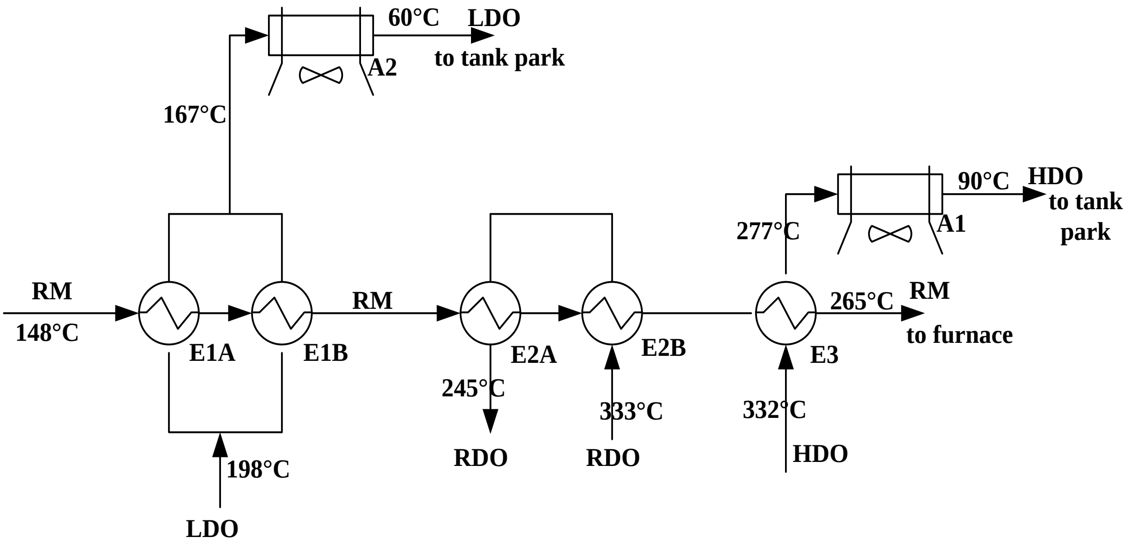


***Figure 1**. Actual System of Heat Recovery - Raw Material Preheating.*

In the heat recovery system presented, a thermal energy reserve is identified that can be recovered. This reserve of thermal energy is observed in the hot flows: LDO, RDO and HDO. Air cooling has a number of disadvantages, including the consumption of electricity and the emission of thermal energy to the environment. This fact determined the finding of some variants for the recovery of the additional thermal energy, from the hot flows and their simulation.

## STUDY CASE – HEAT RECOVERY VARIANTS IN COKING PLANT

Analyzing the actual heat recovery system from the delayed coking plant, two important objectives were established:

1. Simulation of the actual heat recovery system, to start from a real simulated variant.
2. Simulation of a new heat recovery variant for thermal energy efficiency at coking plant.

1. For the first objective, to carry out the simulations, data on the geometry of the heat exchangers, heat exchange (heat transfer areas, inlet - outlet temperatures of the flows), flow rates, physical properties and assay data were required. The specifications required by the PRO/II software were introduced to simulate the actual heat exchange system [8].

The necessary parameters that PRO/II software needs for simulation are presented in tables 1-4.

***Table 1***. *Data for raw material.*

| **E1A,B** | | **E2A,B** | | **E3B** | |
|---|---|---|---|---|---|
| Inlet temperature, °C | **148** | Inlet temperature inlet E2A, °C | **165** | Inlet temperature, °C | **255** |
| Outlet temperature, °C | **165** | Outlet temperature outlet E2B, °C | **255** | Outlet temperature, °C | **265** |
| Pressure, bar | 17.3 | Pressure, bar | 17.3 | Pressure, bar | 17.3 |
| Flow rate, $m^3/h$ | 57.8 | Flow rate, $m^3/h$ | 57.8 | Flow rate, $m^3/h$ | 57.8 |
| Relative density - $d_{15}^{15}$ | 1.138 | | | | |
| Watson Factor de – K | 12.5 | | | | |
| water+ Sediment, % | 0.8 | | | | |

***Table 2***. *Data for hot technological flows.*

| **LDO** | | **HDO** | | **RDO** | |
|---|---|---|---|---|---|
| Temperature inlet E1AB, °C | **198** | Temperature inlet E3B, °C | **332** | Temperature inlet E2A, °C | **333** |
| Temperature outlet E1AB, °C | **167** | Temperature outlet E3B, °C | **277** | Temperature outlet E2B, °C | **245** |
| Pressure, bar | 6 | Pressure, bar | 8 | Pressure, bar | 15 |
| Flow rate, $m^3/h$ | 29.6 | Flow rate, $m^3/h$ | 10.1 | Flow rate, $m^3/h$ | 55 |
| Density - $d_{15}^{15}$ | 0.8698 | Density - $d_{15}^{15}$ | 0.903 | | |
| Watson Factor de – K | 11.5 | Watson Factor de – K | 12 | | |
| Temperature for 0% vol. distilled, °C | 148 | Temperature for 0% vol. distilled, °C | 233 | | |
| Temperature for 94% vol. distilled, °C | 373 | Temperature for 34% vol. distilled, °C | 360 | | |

***Table 3***. *Geometrical specifications of the heat exchangers.*

| **Parameters** | **E1A/E1B** | **E2A/E2B** | **E3B** |
|---|---|---|---|
| Area, $m^2$ | 265/265 | 360/360 | 204 |
| Tube inside diameter, m | 0.02 | 0.02 | 0.02 |
| Tube outside diameter, m | 0.025 | 0.025 | 0.025 |
| Tube Length, m | 6 | 6 | 6 |

***Table 4***. *Assay data for technological flows.*

| **Flow** | **% distilled** | **Temperature, °C** |
|---|---|---|
| Raw Material | 0 | 233 |
| | 34 | 360 |
| Light Diesel Oil | 0 | 148 |
| | 95 | 373 |
| Heavy Diesel Oil | 0 | 225 |
| | 35 | 360 |
| Recirculated Diesel Oil | 0 | 215 |
| | 32 | 319 |

2. The second objective was to improve the heat recovery variant, by proposing the additional recovery of thermal energy from hot streams: light diesel oil, recirculated heavy diesel oil and heavy diesel oil.

Through heat recovery, it was proposed to obtain low-pressure steam, of 4 or 6 bar, and to determine the possible flow rate.

This was achieved by building the process flow diagram (PFD), with the addition of three heat exchangers. Demineralized water feeds exchanger 1E, takes heat from LDO, then in exchanger 2E, takes heat from RDO and in exchanger 3E, takes heat from HDO. The inlet temperatures of the hot streams in exchangers 1E, 2E and 3E are the outlet temperatures of the actual heat exchangers, E1A, E1B, E2A, E2B and E3. Thus, the temperatures of the flows, before entering the air coolers, are lower than in the actual variant.

The process flow diagram is presented in the figure 3 after simulation.

## RESULTS

Simulation of the actual heat regeneration system in the coking plant using the PRO/II software shows in figure 2.

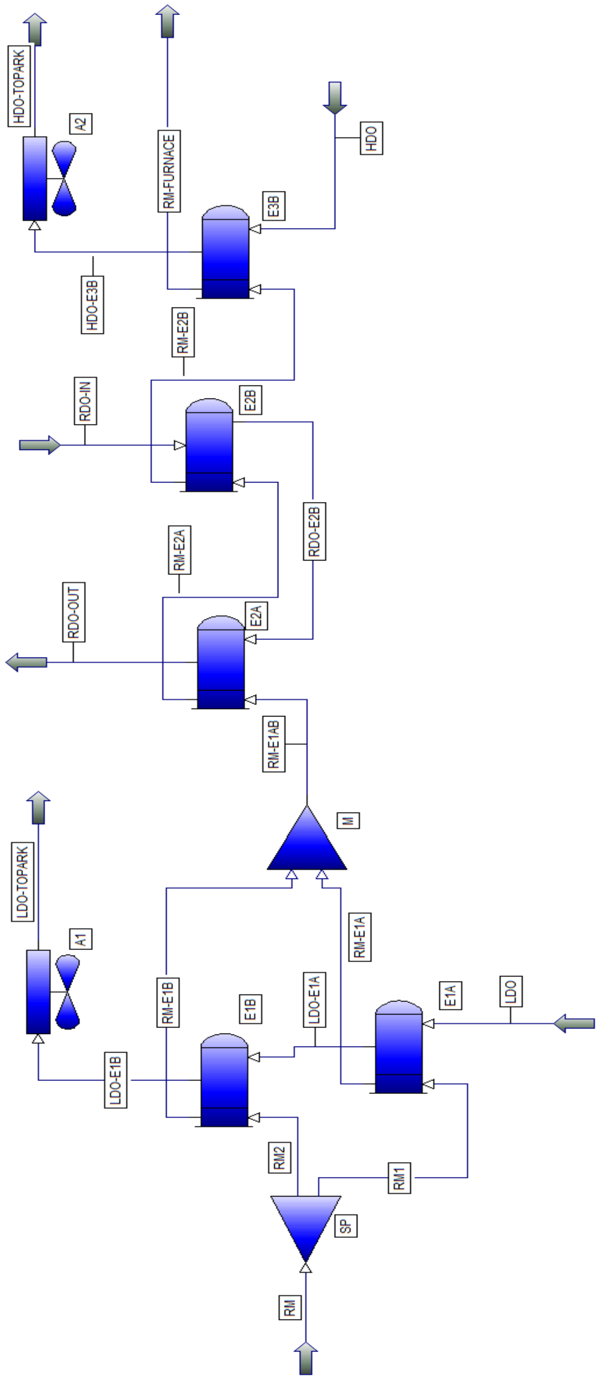


***Figure 2***. *Simulated diagram of the heat exchange system in the current variant. (SP – splitter; M – mixer)*

In tables 5 and 6 are presented the simulation report selection for actual heat recovery system.

*Table 5. Inlet-outlet temperatures of technological flows.*

| Temperatures, °C | E1A | E1B | E2A | E2B | E3B |
|---|---|---|---|---|---|
| Inlet RM | 148 | 148 | 165 | 220 | 255 |
| Outlet RM | **169** | **161** | **220** | **255** | **267** |
| Inlet LDO | 198 | 178 | - | - | - |
| Outlet LDO | 178 | **165** | - | - | - |
| Inlet RDO | - | - | 298 | 333 | - |
| Outlet RDO | - | - | **245** | 298 | - |
| Inlet HDO | - | - | - | - | 332 |
| Outlet HDO | - | - | - | - | **266** |

*Table 6. Results of heat exchangers data for actual variant.*

| RESULTS – ACTUAL VARIANT | | | | | |
|---|---|---|---|---|---|
| **Parameters** | **HEAT EXCHANGERS** | | | | |
| | **E1A** | **E1B** | **E2A** | **E2B** | **E3B** |
| **Thermal energy , kW** | **355** | **218** | **1951** | **1315** | **463** |
| F-Factor | 0.914 | 0.899 | 0.917 | 0.967 | 0.799 |
| Mean temperature difference, °C | 29.49 | 17.21 | 79.58 | 78.36 | 30.5 |
| k, Overall heat transfer coefficient without deposits, W/($m^2$·°C) | 47 | 42 | 80 | 100 | 94 |
| $k_d$ , Overall heat transfer coefficient with deposits, W/($m^2$·°C) | 45 | 41 | 75 | 92 | 88 |
| Area, $m^2$ | 265 | 265 | 360 | 360 | 204 |

The simulation of the actual variant verifies the mode of operation heat recovery system and the resulting parameters can be compared with real parameters from the installation.

Following the actual variant simulation, the flows final temperatures resulted. The raw material temperature at the furnace, the hot streams final temperatures, check the actual outlet temperatures.

## PROPOSED VARIANTS FOR INCREASING RECOVERED THERMAL ENERGY

The process flow diagram for the proposed variant of heat recovery is presented in the figure 3. Within the proposed system, there are three heat exchangers, 1E, 2E and 3E. At the level of these heat exchangers, heat is exchanged between the demineralized water and the hot streams LDO, RDO and HDO, with low-pressure steam being obtained.

Several variants were tried, obtaining different qualities of steam. Two possibilities were chosen, the low pressure steam versions of 4 bar and 6 bar.

Three heat exchangers were needed, because the same geometric sizes of the existing exchangers in the installation were used, similar heat exchange areas, to use existing equipment in the installation or with costs similar to those already existing.

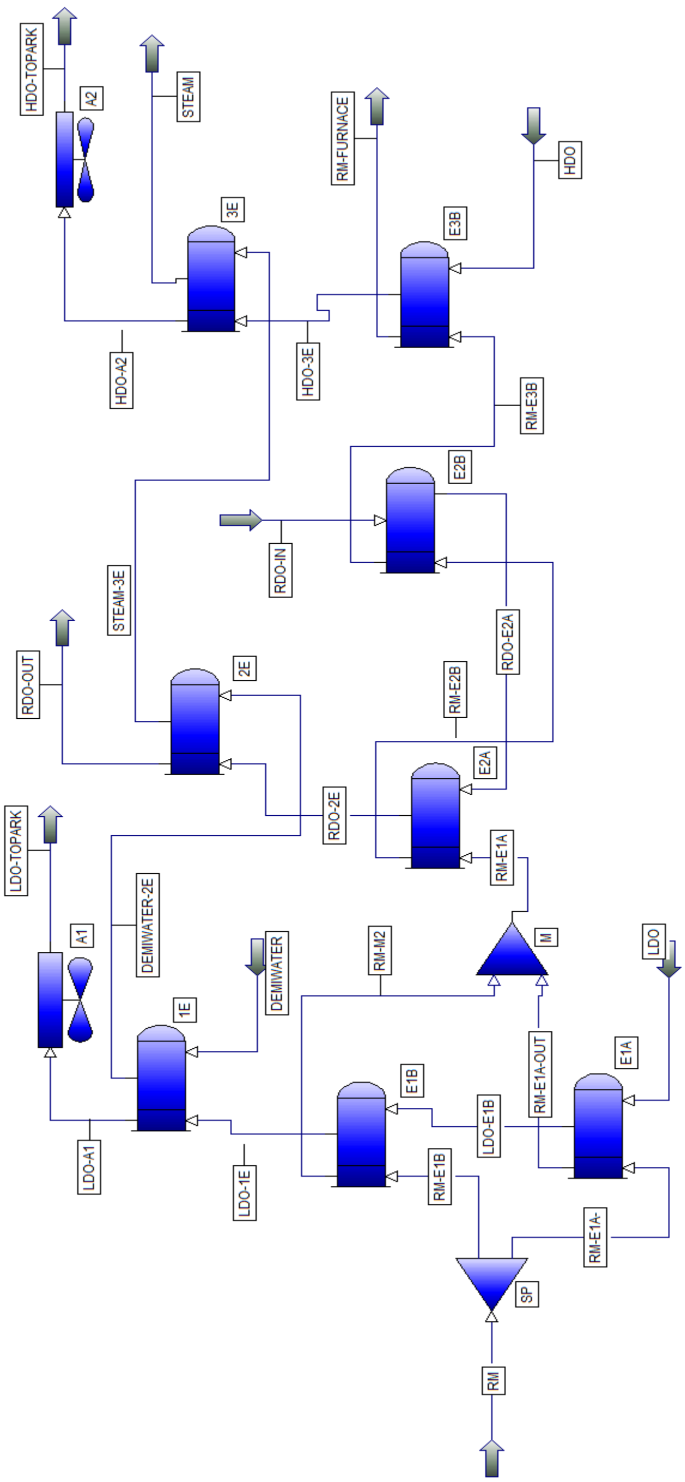


***Figure 3****. Simulated diagram of the heat exchange system with low pressure steam generation, 4 and 6 bar pressure.*

In table 7 are shown the technological flows temperatures resulting from simulations of heat recovery variants, for low steam generation 4 and 6 bar pressure and in table 8 are shown the characteristic heat exchange parameters.

***Table 7***. *Results of technological flows temperatures for 2 variants of low steam generation, 4 and 6 bar.*

| **RESULTS – PROPOSE VARIANT OF LOW STEAM GENERATION 4 BAR** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Temperatures, °C** | **E1A** | **E1B** | **E2A** | **E2B** | **E3B** | **1E** | **2E** | **3E** |
| Inlet RM | 148 | 148 | 165 | 220 | 255 | - | - | - |
| Outlet RM | 169 | 161 | 220 | 255 | 267 | - | - | - |
| Inlet LDO | 198 | 178 | - | - | - | **165** | - | - |
| Outlet LDO | 178 | 165 | - | - | - | **140** | - | - |
| Inlet RDO | - | - | 298 | 333 | - | - | **245** | - |
| Outlet RDO | - | - | 245 | 298 | - | - | **200** | - |
| Inlet HDO | - | - | - | - | 332 | - | - | **266** |
| Outlet HDO | - | - | - | - | 266 | - | - | **170** |
| Inlet water/steam | - | - | - | - | - | **30** | **131.3** | **143** |
| Outlet water/steam | - | - | - | - | - | **131.3** | **143** | **143.5** |
| **RESULTS – PROPOSE VARIANT OF LOW STEAM GENERATION 6 BAR** | | | | | | | | |
| **Temperatures, °C** | **E1A** | **E1B** | **E2A** | **E2B** | **E3B** | **1E** | **2E** | **3E** |
| Inlet RM | 148 | 148 | 165 | 220 | 255 | - | - | - |
| Outlet RM | 169 | 161 | 220 | 255 | 267 | - | - | - |
| Inlet LDO | 198 | 178 | - | - | - | **165** | - | - |
| Outlet LDO | 178 | 165 | - | - | - | **150** | - | - |
| Inlet RDO | - | - | 298 | 333 | - | - | **245** | - |
| Outlet RDO | - | - | 245 | 298 | - | - | **200** | - |
| Inlet HDO | - | - | - | - | 332 | - | - | **266** |
| Outlet HDO | - | - | - | - | 266 | - | - | **179** |
| Inlet water/steam | - | - | - | - | - | **80** | **141** | **158.5** |
| Outlet water/steam | - | - | - | - | - | **141** | **158.5** | **158.8** |

***Table 8***. *Results of heat exchangers data for 2 variants low steam generation, 4 and 6 bar pressure.*

| **RESULTS – PROPOSE VARIANT OF LOW STEAM GENERATION, 4 BAR PRESSURE** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Parameters | **HEAT EXCHANGERS** | | | | | | | |
| | **E1A** | **E1B** | **E2A** | **E2B** | **E3B** | **1E** | **2E** | **3E** |
| **Thermal energy, kW** | **355** | **218** | **1951** | **1315** | **463** | **429** | **1573** | **616** |
| F-Factor | 0.914 | 0.899 | 0.917 | 0.967 | 0.799 | 0.878 | 0.987 | 0.998 |
| Mean temperature difference, °C | 29.49 | 17.21 | 79.58 | 78.36 | 30.5 | 64.85 | 77.31 | 62.88 |
| k, Overall heat transfer coefficient without deposits, $W/(m^2 \cdot °C)$ | 47 | 42 | 80 | 100 | 94 | 71 | 130 | 29 |
| Area, $m^2$ | 265 | 265 | 360 | 360 | 204 | 265 | 360 | 204 |

| RESULTS – PROPOSE VARIANT OF LOW STEAM GENERATION, 6 BAR PRESSURE | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Parameters | **E1A** | **E1B** | **E2A** | **E2B** | **E3B** | **1E** | **2E** | **3E** |
| **Thermal energy , kW** | **355** | **218** | **1951** | **1315** | **463** | **262** | **1573** | **562** |
| F-Factor | 0.914 | 0.899 | 0.917 | 0.967 | 0.799 | 0.901 | 0.973 | 0.998 |
| Mean temperature difference, °C | 29.49 | 17.21 | 79.58 | 78.36 | 30.5 | 42.94 | 61.86 | 52.28 |
| k, Overall heat transfer coefficient without deposits, W/(m$^2$·°C) | 47 | 42 | 80 | 100 | 94 | 71 | 129 | 28 |
| Area, m$^2$ | 265 | 265 | 360 | 360 | 204 | 265 | 360 | 204 |

***Table 9***. *Thermal energy released in air coolers.*

| ACTUAL VARIANT | | |
|---|---|---|
| Parameters | **A1** | **A2** |
| **Thermal energy, kW** | **1144.4** | **1676.5** |
| Factor F | 0.962 | 0.923 |
| Overall heat transfer coefficient, kW/(m$^2$·°C) | 5 | 5 |
| Aria, m$^2$ | 2000 | 4500 |

***Table 10***. *Thermal energy released in air coolers for 2 variants low steam generation, 4 and 6 bar.*

| RESULTS – PROPOSE VARIANT OF LOW STEAM GENERATION, 4 BAR PRESSURE | | | RESULTS – PROPOSE VARIANT OF LOW STEAM GENERATION, 6 BAR PRESSURE | | |
|---|---|---|---|---|---|
| Parameters | **A1** | **A2** | Parameters | **A1** | **A2** |
| **Thermal energy, kW** | **451** | **1231** | **Thermal energy, kW** | **505** | **1398** |
| Factor F | 0.962 | 0.918 | Factor F | 0.962 | 0.92 |
| Overall heat transfer coefficient, kW/(m$^2$·°C) | 3.9 | 4.3 | Overall heat transfer coefficient, kW/(m$^2$·°C) | 4 | 4.5 |
| Area, m$^2$ | 2000 | 4500 | Area, m$^2$ | 2000 | 4500 |

In the tables 9 and 10, the levels of thermal energy discharged to the environment can be observed by comparing the actual variant and the proposed heat recovery variants. The decrease in thermal energy lost to the environment is observed in the proposed variants with low pressure steam generation.

## CONCLUSIONS

Thermal analysis of heat exchange systems in order to find efficient heat regeneration/recovery variants is a necessity for the industry in the actual development context. The study was based on the current system of preheating the raw material in the coking plant. After preheating the raw material, the final temperatures of the hot flows indicate a reserve of thermal energy which can be capitalized.

Two objectives were achieved in the work: the simulation of the current heat recovery system from the delayed coking plant within a refinery and the simulation of a proposed additional heat recovery system.

The second objective was to improve the heat recovery variant, by proposing the additional recovery of thermal energy from hot streams: LDO, RDO, HDO.

The simulation of the thermal energy recovery from technological flows (LDO, RDO, HDO) was carried out with the aim to generate low pressure steam, decreasing of the technological flow temperatures and decreasing of the thermal loads at air coolers.

Through heat recovery, it was proposed to obtain low-pressure steam, of 4 or 6 bar, and to determine the possible flow rate. Low pressure steam has many uses, but the most common is a heating agent and in the refinery a heating agent is necessary.

Simulation variants involve the recovery of thermal energy from hot flows, generating of low pressure steam, around 3.6 t/h flow rate. In the 4 bar steam generation, the proposed variant reduce the heat loss to the environment by approximately 40%. In the 6 bar steam generation, the proposed variant reduce the heat loss to the environment by approximately 35%. And last but not least, by reducing the heat lost to the environment, in the air coolers, the environment is protected.

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